Virtual Laboratory: a virtual distributed platform to share and perform experiments

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ABSTRACT

This paper presents a distributed platform that gives researchers a framework to develop and deploy multi modal enabled experiments (haptic, audio, 3d vision), share them on the network with other research institutes and cooperate or remotely teleoperate with partners during the experiments. It gives also the possibility to see and collect significant data to be analyzed so that it's possible to achieve scientific results. All the experiments performed within the platform are real-time and fully interactive distinguishing the proposed Virtual Laboratory from other virtual laboratories that is possible to find in literature.

The purpose of such platform is to enhance the speed of development of multi modal haptic enabled applications and improve the whole scientific experiment workflow. In particular the Virtual Laboratory platform is intended to supply a common shared place to perform inter-laboratories experiments and enhance the production of scientific results.

KEYWORDS: Haptic, Virtual Environment, Web, Programming.

INDEX TERMS: Haptic Interface, Cooperative Haptics, Collaborative Virtual Environments, Experimental Framework, Virtual Laboratory.

1 INTRODUCTION

In the recent years web applications have grown in number significantly. Web interactive applications in literature are documented mostly as teleoperated systems. Goldberg at al. [2] developed a 3 DOF telerobotic system where users were able to explore a remote world and alter it blowing burst of compressed air into its sand filled world. Another telerobotic system [3] allowed some blocks to be remotely manipulated through the WWW 2.0 using a robot with an attached gripper. The mechanical gaze [4] is a remote environment browser to visit actual remote space and exhibits. Similarly embedded web servers were provided to limit resource space [6]. The LABNET project [5] presented the implementation of a networked laboratory environment to allow easy access and exploitation of remote equipments and testbeds. The integration of haptics with the Web as been addressed by integrating haptic rendering in a VRML browser [7] allowing a specific family of device and specific interaction modalities to be supported.

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Several attempts for distributed VE application development have been made in the recent years both they concern with toolkits[10,12,13,14] as well as complete design systems[9,11,16]. In [26] is presented a peripheral system that is complementary to VR toolkits and aims to provide a uniform interface to a wide range of devices providing a robust, low latency network access to devices.

The growing number of robotic devices connected to the net as well as the development of computer technologies and the Internet quests for a common platform to interact and perform enhanced robotic experiments.

None of the existing environments will allow to share experiments through a fully multi sensorial experience (haptic, audio, video) that includes real-time interaction with remotely located users/environments.

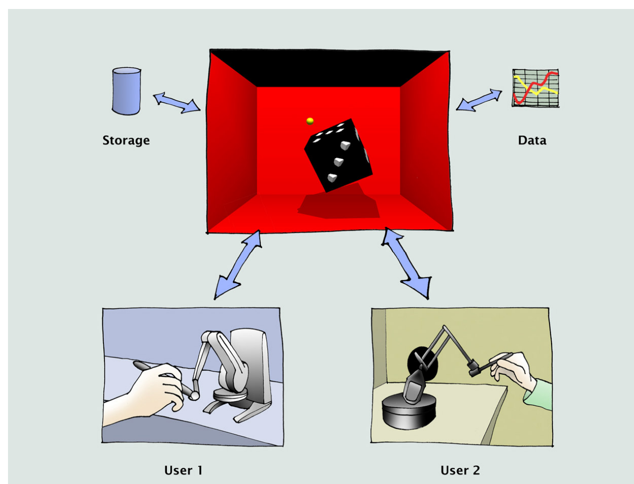


Figure 1. Scheme of concept of the Virtual Laboratory

With the development of new computer technologies and the WorldWideWeb, it is now possible to simulate engineering and science laboratory projects on a computer. With Internet access is possible to offer students or researchers "virtual laboratories" via the web . Experiment-oriented problems can be offered without the overhead incurred when maintaining a full laboratory.

Looking at the "virtual laboratories" panorama present on the web today, there is a lack of functionality when considering fully interactive and real-time shared laboratory. In most of cases what is intended as a virtual laboratory is a Java applet that permits to experiment ad hoc problems for beginning science and engineering students so resulting in a not fully interactive scenario[19,20].

This paper presents a Virtual laboratory that is intended to be a framework that permits to distribute, share and perform experiments with the same facilities as in a real laboratory.

The experiments of the presented virtual laboratory are full real-time and interactive, allow cooperation and analysis during the whole simulation process and permits to collect significant data to achieve scientific results.

This project was motivated by the need of performing common experiments shared between several research centers as in the main intent of the ENACTIVE network itself[25]. So we wanted to develop an easy tool for prototyping haptic enabled experiments and deploy them trough the net, capable of sharing information and results and allowing to perform complex inter-partner cooperative remote experiments as well as to have a common framework to build teleoperation and simulation software. So our first goal was to offer to the research community a shared platform to easily perform experiments and a framework to simplify the entire scientific process related on haptics and virtual reality simulations.

Thanks to the facilities of this platform it's possible to perform experiments with partners worldwide belonging to different research centers as they were on the same laboratory.

The rest of the paper is structured as follows. First we depict the motivations and goals of the project clarifying what enhancements it adds to the current research facilities. We gives a fast overview of what the Virtual Laboratory is and how it works. Subsequently we provided an in depth description on the technology behind the framework and it’s architecture.

2 VIRTUAL LABORATORY

Consider the following scenario, Jim, John and Jack are three researchers active on different fields(computer science, cognitive process, mathematics) living in different countries. They decided to perform an interesting experiment together. Unfortunately, problems crop up. First, because of their jobs, they have not so much available time to do such research and what it’s difficult they should plan the experiment in days in which they both are free from other engagements. Secondly they should find a right location where performing the experiment and check the availability on the chosen days. Also the materials to perform the experiment must be take on the place. After some weeks of contacts for the organization they finally could meet and perform such experiment. They return home enthusiastic of the work done. However when analyzing the results of their experiments they suddenly understood that with slightly changes to the experiment they could have reached much better results. Jack especially is sad for not having recorded the experiment from another point of view with a second camera. They immediately decided that was better to plan another meeting. They wasted a lot of time and resources in the meanwhile and they guess if there exists a tool to share, perform, playback and analyze their experiments without all of these wastes. The proposed Virtual Laboratory(VL) aims to provide them with such tool. The VL has been developed for experimenting virtual reality simulations trough the use of multi modal haptic interfaces. It looks like a shared platform accessible from any web access point, without any specific assumptions on the guest platform, that stores experiments and shares the collected information between the users. The developed system provides basic functionalities to easily perform the different phases of experiment design and trial at distance among users, designer engineers and neuro-scientists.

A more concrete example of the possible usage of the VL is the cubetti demo. In this demo the user has the goal of reconstructing an image divided in equal squares. Several cubes are present in the scene and on each face of the cubes are depicted different parts of the image to be reconstructed. This kind of demo is useful to analyze the choices done by the users to accomplish the task. From where they decided to start reconstructing the image(the bottom or an angle), if they prefer to rotate cubes and change face or if they prefer to use directly the face visible in the reconstruction. So this is an example of non cooperative experiment but that thanks to the distributed approach of the VL can be performed by many people around the world so collecting statistically useful information.

A more interesting experiment that can be conducted is an assembly task where is necessary to cooperate to finish each assembly step cause with an only haptic interface is not possible to move or orientate properly the piece to be assembled. With the VL is possible to join the same experiment from different laboratories around the world and cooperate with the other users each through his own haptic interface to accomplish such task. The interaction is not managed in mutual exclusion but in real time cooperation so that is possible to interact with the virtual scene as well as with the other devices present on the scene and remotely located in the users’ laboratories or offices. The synchronization of the scene is managed by one of the experimenters that assumes the Master role.

The Virtual Laboratory offers a fully multi modal interaction during experiments simulations managing visual, auditory and haptic feedback so that the user can feel a complete perceptual experience.

The VL Web server can provide access to any member connected through the network each one with its own remote desktop or haptic devices. During simulations the framework allows several control monitors to show the remote users with the content of the user interaction in real time so that instructors or analysts can interactively drive the user to perform a correct experiment. Additionally by accessing the system, the different users are allowed to access and control different elements of the virtual space. In this way it allows to design, develop and follow all the phases required to carry out experiments in distributed places.

The VL Platform is organized in distributed modules (Figure 3), an Inter-Partner network will ensure data connection and information security between the partners that joined the Virtual Laboratory. The modules provide distributed access, control and analysis to experimental environments and devices.

The VL can manage different kinds of haptic devices directly by the platform so that in addition to the haptic devices already supported by the framework (more than five different types of HI) it easily interfaces custom driver for additional devices.

From the technological point of view the Framework provides enough extensibility for the integration of new algorithms and modules.

The experiment execution is recorded by the VL storage that stores it on a common resource place for later analysis.

The workflow of a real experiment requires to implement the following phases as depicted in Figure 2. An experiment requires the creation of a specific application with the purpose of evaluating a technology, a theory, a perceptual aspect. In particular the phases of design and setup of the scene (experiment) require short time to be developed trough the virtual laboratory. The trial and analysis phase can be achieved with no added complexity taking relevant data directly from the execution of the experiments. If the analysis lead to reconsider the design , adding or changing some aspects of the experiment is extremely fast to achieve with the platform. Starting from the idea of the experiment all the subsequent phases can be performed trough the use of the Virtual Laboratory platform enhancing each step of the whole process.

The following features were considered for the experimental platform.

For what involves the environment design we wanted to grant an easy way to design the application content so that the overall time spent to develop and deploy an haptic enabled applications could be reduced and a major amount of time can be spent in the trial or analysis phase.

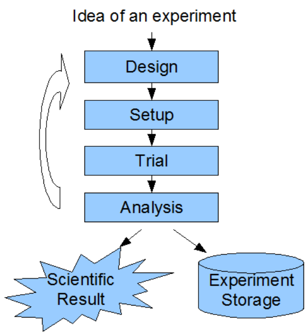


Figure 2.Experiment workflow

The Virtual Laboratory simplify the production stage of the application. The intended experiments of the virtual laboratory should be performed by multiple partners and involve a networked virtual environment as well as the use of different multimodal interfaces and algorithms.

One classical “haptic enabled” VR application is the dice demo The user can move and interact with a big dice floating inside a box environment to test the proper functioning of his haptic device.

This can be developed easily with VL loading in the virtual environment a cube as workspace. The framework allows automatically to insert physical simulation and manage haptic interaction with remote users allowing then to interact directly in the scene not only with an unique interface but in cooperation and in a fully multi users cooperative real time application. So the time to develop the experiment is almost identical to that of develop a single side application with a good framework. The user can immediately start to analyze data from the experiment, and monitor forces and torques during the whole simulation.

3 Architecture

Referring to Figure 3, users access the system by connecting to an on-line web server. The web server grants some facilities. External audio and video communication programs are provided to allow participants to see and talk with users connected on the same experiment. The web site also offers a panoramic of the functionality of the Virtual Laboratory itself. When connected to the laboratory the user is able to see all the working experiments divided in different rooms as it was a real laboratory. For each room there is a short description of the kind of the experiment as well as the capabilities (like maximum number of performers etc..) and it will be shown the current status of the experiment. The experiment could be active and running or the room could be empty. To have access to the experiment the user should have been connected to the Virtual Laboratory “Virtual Private

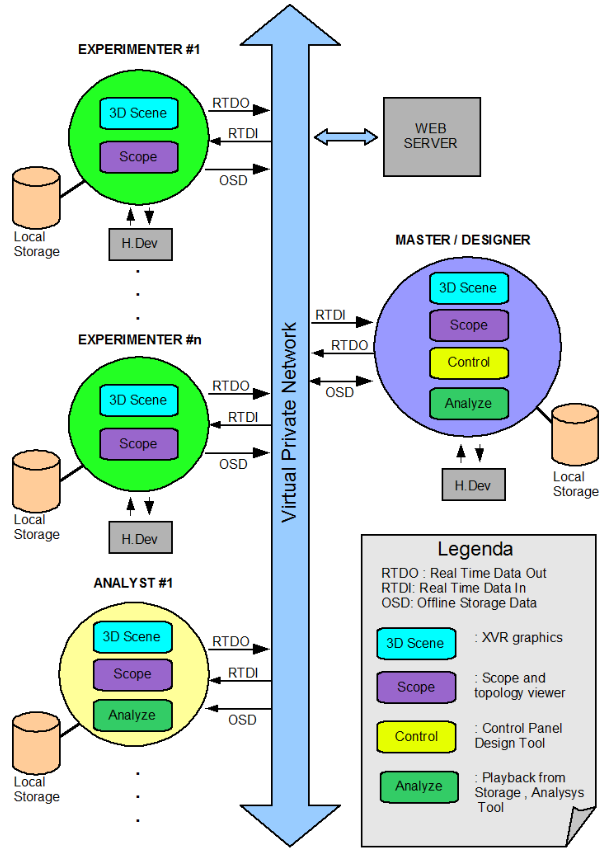


Figure 3. Architecture of the System

Network”. In this way each participant is verified and the access is secured by its own access key and certificate. The VPN use will also allow to have an unique network identification as well as independence from the network infrastructure granting user’s privacy. Each user can choose its role within the experiment (e.g. experimenter, analyst, designer,..). In Figure 3 for example three different roles are depicted. In general the application and user interaction with the experiment will vary based on the chosen role. The Master/Designer should control all the experiment and instruct the experimenters or modify the experiment during execution. Experimenters are the users that take part to the experiment and interact with their own multimodal system. Analysts are researcher as spectator of the experiment and could record and track all the sensible data for scientific purpose. Other roles could be added for specific applications if needed as the framework is easily extensible.

Once entered an experiment all the data exchange will be held by a Communication Server (not shown in Figure 3) present on the VPN. Each data is tagged with the name of the experiment and other relevant information such that server can properly dispatch data to clients connected at different experiments. In this way several experiments could be performed simultaneously. The master application is also responsible of the dynamic physical computation present in the experiment. Each other application assumes the role of a “slave” application, receives from the communication server all data produced by the master and interpolates physical data to keep believable the physical evolution of the scene during simulation.

Each participant exchanges real time data needed for the experiment execution trough the communication channel opened with the Communication Server while in the meantime the application saves all the relevant data in a local storage so that for each participant there are one or more data log files collecting user interaction information.

Alternatively the storage could be local requiring therefore an upload to the server at the end of each experiment. The experiments applications run as embedded plugins inside the browser and the web pages of the Virtual Laboratory site. This is possible through the use of the eXtreme Virtual Reality [1] framework and the HapticWeb extension documented in [8]. Physical based modelling simulation engines are also integrated [24].

Presently, according to its role each participant can share a different set of data types (see figure 4):

- Analysis data is related to the analysis of performance, evaluation of correct sequence of action performed by participants and other analysis activities;
- control data allows designers and masters users to modify and control the experiment execution interactively;
- scope data is the data used for real-time plotting of useful information during the experiment and is shown in embedded monitors on the running application;
- 3D Scene data is exchanged across the network to refresh the visual update of the virtual scene.

4 Implementation

The Virtual Laboratory framework is made by several modules written using s3d scripting language of XVR (figure 4), a Javascript like scripting language that can be directly compiled in a multi platform bytecode and than executed from the XVR virtual machine. This guarantees that the execution of the program takes place entirely inside the Web Browser's plugin and that it could be accessed directly from the Virtual Laboratory website.

XVR was choosen since its performances were been proven in many Virtual Reality projects running on the Web and in immersive VR installations [18].

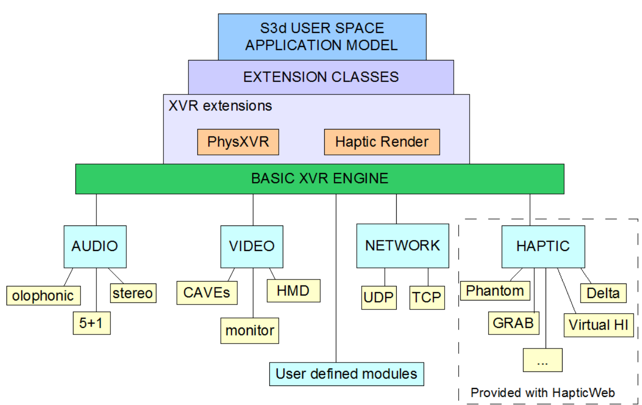


Figure 4. VL Framework software modules

XVR applications reflects the multirate behavior of multimodal applications and are organized around callback functions invoked at specific timed events. Two specific callbacks are associated with the major logical loops: the graphics loops that runs at display refresh rate and the timer loop that can be run at 1 KHz.

The XVR engine provides basic facilities for graphics and spatialized audio. The developer have access to the low level OpenGL API commands as well as the possibility to visualize complex multi textured animated models imported from the most common 3D modelers. The engine provides also the standard optimized scene graph approach to present the Virtual scene on the screen.

For granting realistic Physical Simulation several physical engines are available to use. Embedded on the XVR platform there is the Tokamak engine and the ODE engine and shipped with the Virtual Laboratory there is a porting of the AGEIA PhysX engine to be used in XVR.

Through the use of these dynamic simulators it is possible to simulate real worlds with accuracy even in complex tasks as working with multibody [24] or fluid dynamics.

For the Haptic interaction and rendering, the Virtual Laboratory make use of the HapticWeb module to manage the device interaction with the scene.

Using HapticWeb allows a seamless integration with a big number of devices in the Virtual Laboratory and also provides different choices for the implementation of the haptic loop. When no device is specified by the developer HapticWeb scans the attached peripherals to automatically identify the type of the device and automatically configure the application. If no recognized device is present at all the HapticWeb provides a virtual device that can be used trough a standard or a 6DOF mouse.

HapticWeb solves also multithreading problems by implementing a two Virtual Machine approach. The main Virtual Machine is devoted to the graphic loop as well as the control of other peripherals while the secondary Virtual Machine is isolated from the first, it runs in another thread and is responsible of the Haptic loop. The communication between the two Virtual Machines is performed by a shared memory mechanism and is shown in Figure 5.

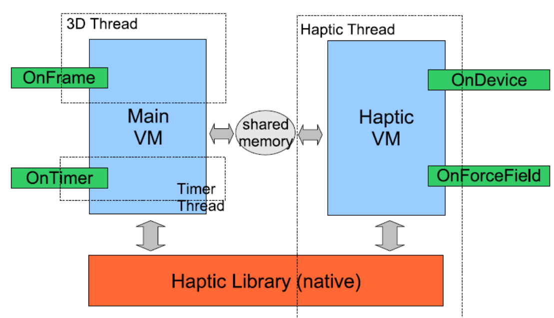


Figure 5. The two Virtual Machine approach

In the communication layer we distinguished the information exchange between the application and the haptic interface and the application and the other connected users. For the Haptic control we decided to adopt a fast real time transmission via the use of UDP transmission packets to be able to grant an almost responsive system and to maintain the stability in the loop. For the inter-partners information exchange we adopted a reliable TCP connection with a Communication Server that re-transmit all the received information to the users connected on the same experiment channel so that each participant can refresh the current status of the experiment. From the extensibility point of view every specialized piece of code can be embedded in the VL framework with a simple interface code that requires very basic programming skills. The same can be told for the integration of a custom haptic interface, requiring to specify physical properties of the device as well as to declare the function to get/set position, forces and all the other relevant information used by the haptic interface or software application. For the analysis phase the standard scope shows position and forces of each device connected as well as network statistics. All the information to be plotted and to be saved in the storage can be customized with a few lines of code choosing exactly what kind of information is requested. The compilation of the custom code within the framework to bytecode last few seconds and doesn't requires special software in addition to the XVR script editor. All the framework is free to download and to use. A graphical editor is being developed to allow the generation of the graphical and physical scene without any lines of code.

The assessment phase of each experiment is reached through the possibility to retrieve the experiment real-time data, analytic and real-time data display. All the stored data will be available for analysis to each logged participant being part of the Virtual Private Network as plain text files for direct usage with analysis programs such as Matlab.

We did not cope with latencies on stabilities of haptic interaction with the Virtual Laboratory framework since they have been already covered with several approach at state of the art ([21], [22], [23]).

5 Demonstration

A first experiment, the Temple demo, for the Virtual Lab was made to show the capabilities of the VL platform itself. The demo was developed to test the cooperation between several haptic devices and several participants located remotely in the Web.

Figure 6. Temple demo virtual scene

Several tests were made to measure the latency of connection as well as the maximum manageable number of participants by the Communication Server so that we could achieve an almost real-time update of the virtual scene without feeling a noisy lag.

The experiment presented the users with a grass field with some ancient columns (Figure 6), one of them is in its original form while the others are broken into three different pieces.

Each logged experimenter can than touch grasp and move through its own haptic device every object in the scene and interact haptically with the other users. The scope of the demo is than to cooperate to assemble in the right way all the broken columns (cooperation and synchronization issues have been treated in [16],[17]).

During the simulation each participant can choose to see the real time data logging shown in Figure 7. The scope can permit to plot real time graphs to analyze network packets exchanged trough the time distinguished by the type of packet while other graphs are displaying forces and positions of each device present in the simulation.

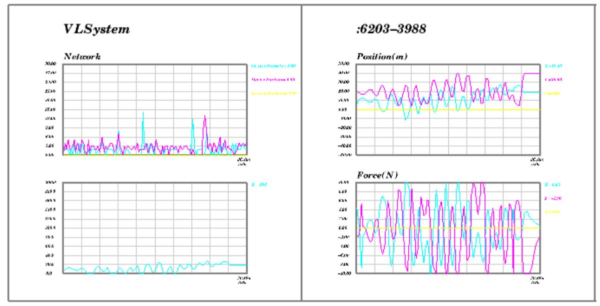


Figure 7. Real Time Scope

Concurrently the demo saves a log text file with all the data visible in the graphs as well as other useful information for later analysis.

Figure 8 shows some users interacting together in the same scene with several haptic interfaces.

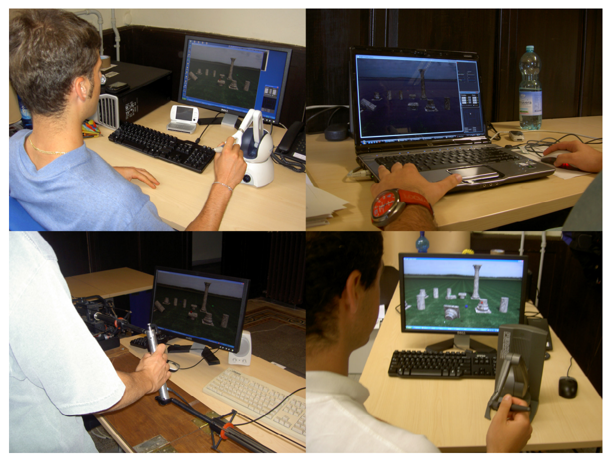


Figure 8. Four users cooperating on the same scene

6 Results

Temple demo was fully working with five experimenters cooperating together, it supports currently more than five different haptic devices and is possible to store a great number of trials for analysing the experiments itself.

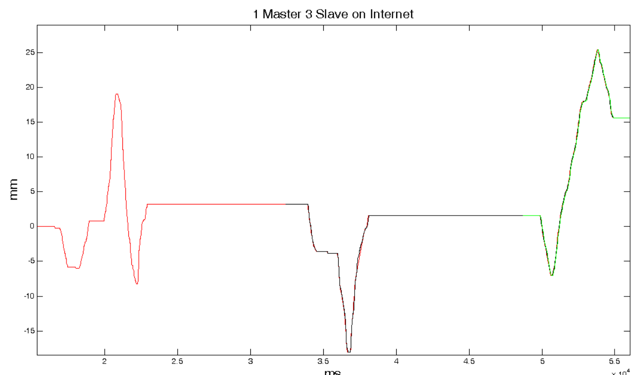
The overhead performances of the Virtual Laboratory architecture have been tested by comparing its architecture to a standard local network (fast Ethernet 100Mb/s- 1Gb/s).

We started analyzing synchronization between each participant of the same experiment to check data collection's delays.

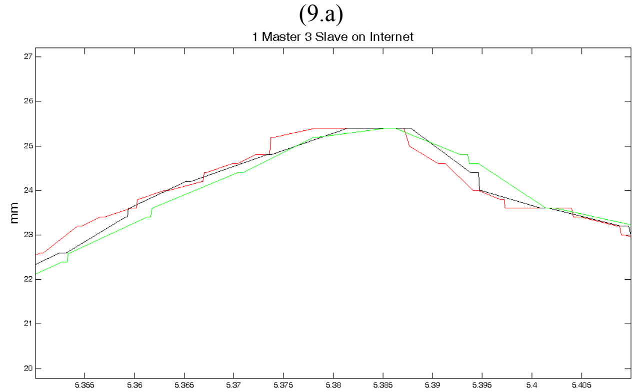
Tests were made growing up progressively the complexity of the network. We did not notice meaningful difference changing the number of performers from 1 master and 1 slave to 1 master and 3 slaves. Subsequent figures depict data retrieve in the performed tests. In particular is shown the synchronization in position of an haptic device end effector seen by the several slaves participants(figures 9,10). The slaves entered the simulation progressively as shown in the figures. The delays encountered with an underlying transmission network topology passing through internet are similar to the ones encountered on LAN tests. The average delays presented were of the order of 15-18 ms on the internet case and of 8-10 ms on the LAN tests. In most of cases the logging itself was not capable of capture instantaneously the data so that we recognize false delay in the plots. Maximum delays encountered are similar and present themselves in sporadic time event. During simulation the communication server reported a maximum incoming bandwidth of nearly 900 Kbps and a maximum outgoing bandwidth of 1900 Kbps.

Even when we are in presence of delays the haptic loop is maintained stable being processed locally at a fast 1KHz rate. Other tests were intended to investigate the delays and eventual errors involved during the interpolation of physical data by the slaves(figure 11). As written above the real physical simulation is performed exclusively by the master application. Each slave should then retrieve physical data from the communication server and interpolate it to maintain simulation consistence.

Looking at last plots we can compare slave's retrieved data with the original physical data produced by the master. The data differs only for low delays shift and quantization effects.

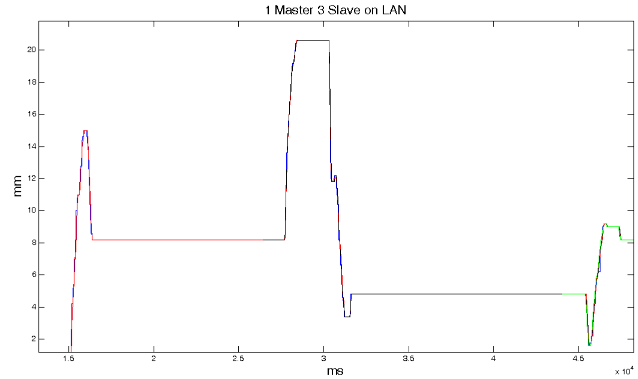


(9.a)

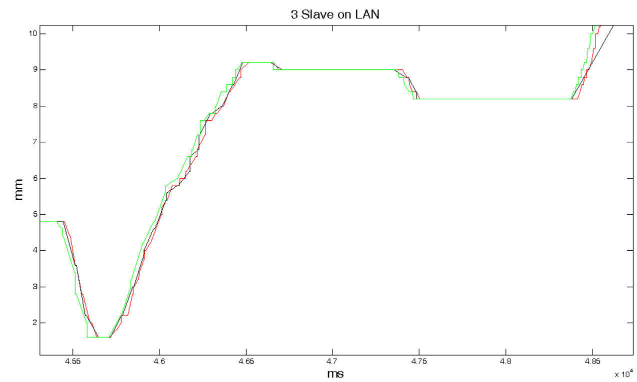


(9.b)

Figure 9.(a) Position of an HI EE as seen during the simulation by each participant. Slaves enters the simulation at 15 , 33 , 48 seconds respectively. Master and slaves applications were running on Windows Vista / XP on intel Core 2 machines. The Communication server residing on the internet at specific address. (b) Closer view of the simulation results presented.

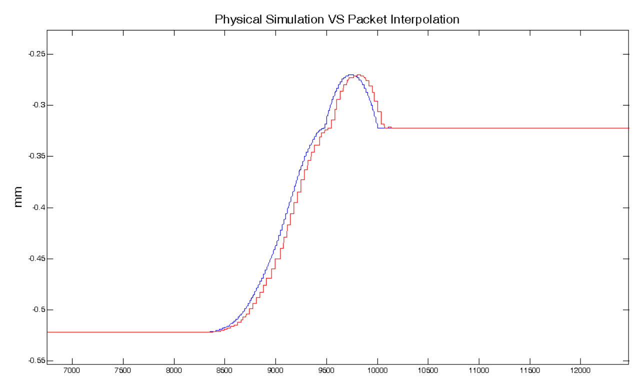


(10.a)

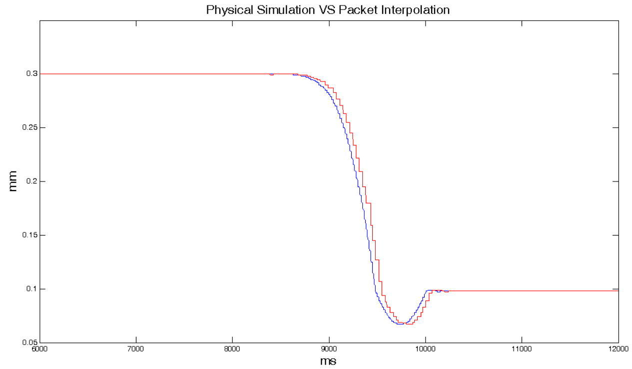


(10.b)

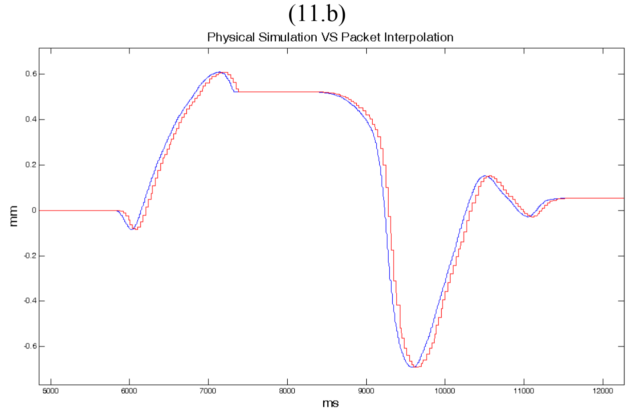
Figure 10. (a) Position of an HI EE as seen during the simulation by each participant. Slaves enters the simulation at 15, 27, 44 seconds respectively. The machines used are the same as for previous analysis. The Communication server resides on LAN.
(b) Closer view of the simulation results presented. Delays are more strict related to the internet case(figure 9).



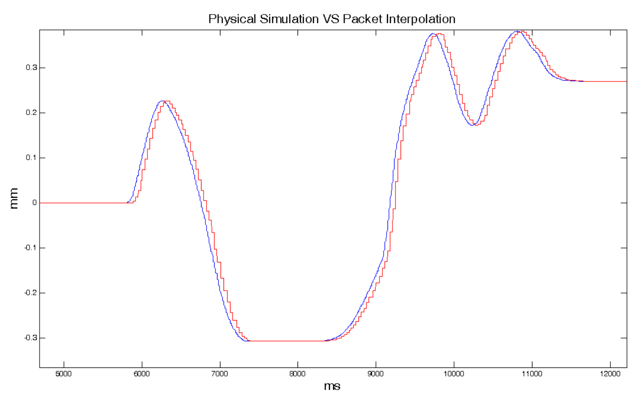
(11.a)



(11.b)



(11.c)



(11.d)

Figure 11. Interpolation of physical data received from master application. Delays are bounded and the simulation coherent.
(a,b) Movements on X and Y axes of a physical object as seen by a slave application compared to the original data calculated on the master application. (c,d) Movements on X and Y axes of a second object.

7 Conclusion

We have presented a new architecture that allows to share and carry out multi sensory experiments across the network.
The Virtual Laboratory is a fully featured real time distributed virtual platform that allows researchers to deploy, share and perform a large number of experiments interacting with multi modal devices and with several users living in different places.
The benchmarking tests show that achieved performance are good enough to carry out medium size of cooperative haptic interactions (3 to 6 active nodes). Any number of analyst or designer nodes (low or passive frequency) is supported.
Persistent storage allows to playback experiments simulations and perform off-line computation of data for analysis purposes.
Strong facilities are grant to develop and carry out all phases of common scientific experiment workflow. The real assessment of the Virtual Laboratory platform it will come with the first scientific results achievements.

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